International Aircraft Materials Fire Test Working Group

Material Systems Renovation and Repair Subgroup

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16. Abstract

This report summarizes the findings of Subgroup 4 of the International Materials Fire Test Working Group, which deals with issues involving fire test approval following renovation and repair to interior material systems. The main problem associated with material system renovation is the difficulty in conducting certification tests due to lack of the appropriate base substrate. The subgroup investigated this problem and made suggestions of alternate testing methods which ranged from the use of a singular common substrate to the use of multiple substrates, or *surrogates,* to run the certification tests on. The use of surrogate materials, although complex, was the only testing method discussed which could insure that a renovated system would remain in compliance without actually testing the final, in-service material system.

Fire test approval following repair of interior systems was another problem area. Most repairs involve the use of plastic-based fillers which are used to fix cracks and dents in panels and also to smooth surfaces prior to finishing with paints or laminates. Currently, there is no test method for certifying the use of fillers, which have the potential to increase the heat release rate and smoke production of interior panels. The subgroup participants discussed possible testing methods for certifying fillers including the system format and the spatula filler only format, but remained divided on the issue. In order to establish the pass/fail criteria for the filler-only method, several different types of spatula fillers were tested, and the results indicate that a majority of the fillers could only pass the 100/100 criteria in the OSU apparatus.

Fire test approval following repair of cargo compartment liners was another issue investigated by the subgroup. In contrast to interior panel repair, there *is* currently a test procedure for certifying repairs made on cargo liners, which generally consist of adhesive patches placed over damaged areas. The current certification procedure encompasses two tests: one for patch material burnthrough resistance, the second for patch adhesion. In addition to this procedure, the subgroup made several recommendations to insure that repairs which meet the certification test will not catastrophically fail during actual fire conditions.

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EXECUTIVE SUMMARY

In an effort to simplify the often complex task of certifying material fire testing methods throughout the aviation/aerospace industry, the International Aircraft Materials Fire Test Working Group was formed. The scope of the working group encompasses the standardization of FAA certification procedures of all material fire tests as well as the solving of new problems which exist with the current test methods. The working group investigates such tests as the Bunsen burner, the 2-gallon-per-hour seat fire blocking and cargo liner tests, the OSU rate of heat release apparatus, and the NBS smoke chamber. Due to the ever-changing environment in which materials are developed, it is often necessary to make adjustments and refinements to these certification tests to accommodate state-of-the-art materials used in the latest cabin interior systems. There is also a high level of complexity associated with these and other fire tests, and unforeseen problems often arise that need to be addressed to insure that certification tests conducted throughout the United States and foreign countries are performed equally and consistently, according to the intent of the FAR's.

In addition to the cultivation of certification testing methods and related equipment, the International Aircraft Materials Fire Test Working Group was tasked to investigate problems in a variety of areas as part of harmonization work involving the FAA and the Joint Airworthiness Authorities (JAA). These areas were broken down into four categories, and individual subgroups were formed to investigate issues in continued compliance (subgroup 1), minor changes to qualified systems (subgroup 2), quality control (subgroup 3), and material systems renovation and repair (subgroup 4). This report discusses the problems, testing performed, findings, and recommendations of Subgroup 4, Material Systems Renovation and Repair. The intent of this subgroup is to clarify and, in some cases, establish certification testing procedures/guidelines for renovated/repaired interior material systems based on technical information.

The subgroup focused on three main topics: (1) the problems associated with the certification of renovated/refurbished interior material systems and, more specifically, the method of conducting certification tests when original substrate materials are unavailable, (2) problems with the development of a certification test for plastic-based fillers and the certification of repairs made to interior material systems using plastic-based fillers prior to refurbishment, and (3) repair of cargo compartment liners and the need for additional procedures to the current test method.

While it is not possible for FAA Aircraft Certification Officers to remove materials from transport aircraft, run OSU/NBS tests, and reinstall these materials back in the aircraft due to the destructive nature of the tests, it is possible to have an established set of guidelines to follow prior to initiating repairs or renovations to cabin material systems to insure compliance. In order for the guidelines to be effective, they must be simple and straightforward, as the airlines are often under very strict time constraints. The recommendations discussed in this report are likely to be included in the Aircraft Materials Fire Test Handbook, which in turn will probably become the principal referenced document in an FAA advisory circular on flammability. As such, it would become part of official FAA guidance on these issues.

INTRODUCTION

PURPOSE.

The purpose of this report is to summarize the findings of the Material Systems Renovation and Repair Subgroup of the International Aircraft Materials Fire Test Working Group. The subgroup's function is to investigate the problems associated with fire test approval of repaired and renovated cabin interior material systems and make recommendations on certification test methodology. The recommendations would be used as the basis for guidance material to be included in the Aircraft Materials Fire Test Handbook.

It is not the subgroup's intention to review fire test approval data on specific repairs and renovations in order to make determinations as to whether or not these procedures result in material systems which remain in compliance; this is the responsibility of the aviation authorities. While there is a great deal of material test data available on repair/renovations and their impact on the heat release rate and smoke production, the data are limited to the specific panel substrate, laminate type, paint type, thickness of paint, etc. It is not within the scope of the subgroup to review and evaluate each and every process that takes place, but to simply *review the types of problems that are presently being encountered and develop guidelines that would ensure the renovated/repaired systems would remain in compliance.* This has often been a very difficult task since the guidelines must be general enough to encompass a broad array of materials, yet specific enough to ensure compliance of the finished renovated/repaired system.

BACKGROUND.

An important cabin fire safety rule change was implemented in 1988 and 1990. This two-tiered rule change prescribed the use of interior panels with a maximum peak heat release rate of 100 kW/m^2 and maximum total heat release of 100 $kW\text{-}min/m^2$ in aircraft manufactured on or after August 20, 1988. Aircraft manufactured on or after August 20, 1990, were required to use interior panels with a maximum peak heat release rate of 65 kW/m^2 and a maximum total heat release of 65 $kW\text{-}min/m^2$ to assure a more fire retardent aircraft interior in the event of a postcrash cabin fire. The rule change focused on large surface area panels used in areas such as sidewalls, ceilings, and stowage bin doors which have a tendency to dominate the growth of a cabin fire. Based on full-scale tests conducted at the FAA Technical Center, low heat release panels that meet the new flammability standard have been found to significantly increase the amount of available escape time in a postcrash fire. Due to the highly unfavorable cost-to-benefit ratio which would result if the improved materials were required to be retrofitted into the existing air carrier fleet, the FAA has not required a mandatory retrofit. Instead, it required that the improved materials be installed in newly manufactured airplanes, and in existing airplanes which undergo a "substantially complete replacement." More recently, airlines faced with stringent cost-cutting measures in order to maintain profit margins have been refurbishing older interiors through the use of paints and decorative laminates. Since these processes would not be considered a substantially complete replacement, the materials used would be required to pass the flammability standards based on the aircraft's type certification only. An airline could thereby achieve a very

contemporary looking interior by simply installing a decorative laminate or paint over the existing interior panels, alleviating the installation of more costly, advanced technology materials.

Another important rule change was implemented in 1991, which addresses the burnthrough resistance of cargo compartment liners in in-service aircraft. The new standard subjects the liner system to realistic flame temperature and heat flux, based on full-scale tests conducted at the FAA Technical Center in simulated class C and D compartments. Because cargo liners are used in high wear areas, they often become damaged over a period of time, usually in the form of rips, tears, and punctures. Most forms of liner damage can be repaired; however, it is critical that the repaired liner system maintain compliance to insure that the compartment can safely contain a fire. As is the case with the interior panels, it is often less costly to repair a damaged cargo liner than to replace it, and testing procedures are currently in place to certify cargo liner repairing systems. The subgroup has been investigating these procedures to ensure that repairs made to newer types of liner materials will also result in a system capable of safely containing a fire.

DISCUSSION

INTERIOR RENOVATION.

From a regulatory standpoint, the process of renovating/refurbishing an aircraft interior raises several concerns. The most important is that the airplane must continue to comply with the flammability requirements contained in its type certification basis and, if applicable (i.e., if the airplane is operated under part 121 and was manufactured on or after August 20, 1988), the requirements of 121.312(a). Therefore, for airplanes with a type certification basis which includes Amendment 25-61 and later or which must comply with 121.312(a), any renovation or refurbishment or repair of the major interior components must continue to meet either 100/100 or 65/65/200 requirements[1]. These requirements necessitate ongoing testing with the OSU and, if applicable, smoke emissions tests to ensure that the refurbished material system is still in compliance. As is often the case with older aircraft, the exact replacement panel types are no longer produced, or worse yet, the manufacturer of the originals has gone out of business. If the original base panels are not available, how then are the certification tests run to insure compliance? This has been a major issue raised by members of the renovation and repair subgroup. Several potential solutions have been introduced with regard to this problem; the following is a summation of these potential solutions as well as the problems associated with each.

Faced with the problem of having an insufficient supply of the exact interior panels required to conduct certification tests, some carriers have reportedly removed existing sidewall, ceiling, and

[1] An aircraft interior which was certified prior to the 65/65/200 rule change does not have to meet this requirement unless a "substantially complete replacement" of the aircraft's interior system takes place. An operator can remove and replace parts of the aircraft interior at different times, e.g., the ceiling panels, then the bins, and then the sidewall panels and be exempt from meeting the upgraded standard. If, however, the operator removes a majority of the interior panels for replacement purposes, the new panels would have to meet the more stringent 65/65/200 test criteria. Most airlines would convert to a more modern look if they were to go through the expense of a complete replacement program, but if they desire the old style interior and wish to keep it, they would have to upgrade the materials.

stowage bin panels and used them to perform the required certification tests with the new decoratives or paints. This can be an expensive process for both the major carriers as well as the regional ones with much smaller fleets. To compound this situation, it is often very difficult to obtain the desired amount of flat surface necessary to conduct the required OSU rate of heat release test (or NBS smoke chamber test) from contoured sidewall or stowage bin panels.

Other subgroup participants support the use of a *common substrate* to run similarity tests for certifying the system renovation in the event that original base panel test coupons are unavailable. This would indeed simplify the certification process, but in most cases would be very unrealistic since the various laminates and paints may react quite differently when applied over different forms of base panels. A decorative which produces very low heat release numbers combined with a graphite based substrate, for example, may indeed produce very high numbers in conjunction with another fiberglass-based substrate panel due to the *synergistic* effects of the materials. Furthermore, what level of heat release rate would be expected of the common substrate so as to be suitable for everyone? A common substrate which exhibits very low heat release numbers of around 30/30 may increase to 40/40 in conjunction with a decorative laminate and still easily meet the 65/65 requirement. What happens if this decorative is now used in the aircraft on panels which are already 63/63 for example? The final combination would likely exceed the 65/65 limit and it would not be apparent using this common substrate form of certification testing. Conversely, several group members suggested that if the decorative or paint results in any heat release increase, it cannot be used on the in-service panels at all. This, too, was unrealistic since any amount of decorative which uses an adhesive to bond to the base panel surface is likely to cause an increase in the heat release rate of the finished system.

In order to overcome the problems associated with using a single, common substrate, other group members suggested the use of several *standard panels* to allow for a history of the decorative laminate or paint to be developed. By running the decorative or paint on three (or more) standard substrates, the synergistic potential could be reduced (i.e., an unfavorable finished material system consisting of the decorative or paint and the actual aircraft panel would more likely be detected by using three or more different types of substrates). The subgroup felt that aluminum, honeycomb, and crush core standard substrates would provide a good cross section of substrates with which to perform qualification tests. Data from these tests would be compared to the original OSU heat release data of the panels used in the aircraft, and an *estimate* of the heat release rate of the final system could be calculated. If the decorative or paint caused an increase of 15/15 units (worst case of the three tests), for example, then it could be used on interior panels with OSU heat release numbers no greater than 50/50 or 85/85 (corresponding to panels required to meet 65/65 and 100/100 respectively). This concept was further refined through subsequent working group meetings, and after several iterations, a straightforward approach based on many of the earlier suggestions was tentatively agreed upon.

Prior to finalizing this test method, the subgroup discussed a procedure for certifying an interior renovation by employing the use of three different types of substitute panels, or *surrogates*, from the same panel family or composition as the original (either a honeycomb, crush core, or thermoplastic). The renovation scheme would be applied to at least two specimens each of the three surrogates; the worst case *increase* for both total heat release and peak heat release would

be added to the original panel OSU data, along with a *safety factor* of 5/5 to account for any synergistic effects that may occur (figure 1). The 5/5 safety factor was agreed upon by group members after discussions with engineers from a major decorative laminate manufacturer. The engineers explained that 5/5 is generally accepted throughout industry as a reasonable standard deviation for this type of testing, but is used in this application to account for the potential synergy problems.

As an example of this procedure, take the case of an operator that wishes to refurbish the interior of its 65/65/200 type-certified aircraft by applying a new decorative laminate over its fiberglass/phenolic resin crush core sidewall panels, but does not have a sufficient quantity of the original base panel material to conduct the certification tests. According to the method discussed, the operator must obtain three different crush core panels, all fiberglass/phenolic, and all of which yield OSU heat release numbers within ±10 percent of the original base crush core sidewall panel. Prior to testing with the decorative scheme, baseline tests must be run. In this example, the first surrogate panel yields baseline numbers of 35/35, the second surrogate 30/30, and the third 20/20. Next, the decorative scheme is applied to the three surrogates, and the tests are repeated, with the first surrogate and decorative producing 60/60, the second one 57/57, and the third one 49/49. From this example, the highest increase resulted with substrate panel 3, in which the decorative scheme caused an increase of 29/29. These numbers would be added to a safety factor of 5/5, producing a grand total of 34/34. This 34/34 would, in turn, be added to the original OSU heat release numbers, in this case 25/30. The final numeric outcome in this example would be 59/64, an acceptable renovation procedure for a 65/65/200 type-certified aircraft (figure 1).

This procedure would work well in theory, providing a comprehensive approach to certifying material combinations without the base substrate. In practice, however, it presents a difficult situation for two reasons. First, the key constituent in this test procedure involves the comparison of surrogate panel test data to the *original* base panel test data. The problem is that this data is unavailable in most cases since the airframe manufacturers are required to provide data on the original panel *system* only. In other words, a newly certified aircraft possesses OSU data on the interior sidewall panel or stowage bin door which consists of a base panel with decorative laminate. *There is no breakdown of data on the individual components*, making this type of certification procedure impossible. Second, several subgroup members with extensive test experience insist that OSU numbers are not additive; therefore, numeric calculations such as these are inaccurate. The only possible alternative would be to test the laminate or paint on the three surrogates, and add the 5/5 synergistic safety factor to obtain a final number thus eliminating the calculation of a final number based on the original base panel data. The highest average (with a minimum of two specimens per surrogate) for both total and peak heat release from any of the three types of surrogate panels would be recorded. Both numbers would have to meet the applicable heat release requirements (figure 2). The one major drawback to this method of testing is that although the final heat release of the renovated system depends mostly on the laminate or paint that is used, it also depends slightly on the particular substrates that are used. Testers may try to use the lowest heat release rate surrogates that are available to pass the test. Therefore, the honeycomb and crush core surrogates should be identified by their core thickness, the number of plies of prepreg per side, and the type reinforcement (carbon or glass) used. In other words, the surrogate panel should replicate the in-service panel as close as possible in terms of panel lay up.

This certification process would have to be repeated for any other materials in the aircraft where the original substrates cannot be obtained. In the above mentioned case, for example, additional certification tests would have to be run if the same decorative laminate was to be used on thermoplastic ceiling panels, honeycomb stowage bin doors, galley panels, etc. The process would be applicable only when the original substrate is unavailable, but the original OSU test data *is* available. *It would not be permissible if the original interior panels are lacking OSU testing data.* This would indicate that the interior panels are very old (pre low heat release type), and could not meet the upgraded flammability requirements anyway.

Several operators participating in the subgroup meetings discussed problems with this latest proposed qualification method. In particular, these operators discussed how some of their 65/65/200 type-certified interiors are already very close to the 65/65 limit. They expressed their concern over not being able to meet the proposed criteria in the event they wish to refurbish their interior since some of their aircraft's interior sidewall panels cannot be stripped of the original decorative laminates (many Boeing manufactured panels cannot be stripped of their decoratives since they are bonded using a two-part thermoset adhesive, necessitating the piggybacking of new laminates over the existing ones; Airbus manufactured panels are strippable from the passenger service unit (PSU) down, and Douglas panels are completely strippable). In many cases the operators claim that an additional decorative piggybacked over the existing one or painting of these panels is their only option for refurbishing.[2] The operators claim that either of these two options is likely to raise the numbers above the 65/65 limit and most are already hesitant at piggybacking since it adds weight. The only other option the operator has if his interior is showing signs of wear is to replace the worn panels with new ones supplied by the airframe manufacturer. This could prove to be rather costly. Additionally, the operators explained their reluctance to replace worn panels with new ones as the colors often don't match up exactly due to the ultraviolet degrading of the surface of the original panels. One operator proposed that the refurbished interiors be qualified on a percentage basis (i.e., if the average surface area of all the panels does not exceed 65/65, then some areas could be permitted to exceed 65/65, provided they don't exceed 70/70 or 75/75, for example). This would cause a very complicated qualification procedure since the actual surface area of the panels which exceed 65/65 would have to be calculated as well as the surface area of the cabin interior, etc. Although this method was not being discussed further at the time of this writing, it has not been ruled out entirely.

The necessity to run smoke tests on renovated interior systems depends on the type certification of the aircraft. If the original type certification of the aircraft is 100/100, no smoke testing is required on the renovated system; if it is 65/65/200, additional smoke testing would be required. In the above example the aircraft was type-certified 65/65/200, and the original crush core sidewall panel substrates were not available, necessitating the use of surrogates for heat release testing. Since further smoke tests would be required in this example, the easiest method would be to use the same three surrogate substrates. In an effort to simplify the certification process, the smoke requirement should follow the same logic as the heat release requirement. In other words, the worst case of the three surrogates (with a minimum of 2 specimens per surrogate) plus a

[2] A major airframe manufacturer has recommended the use of a foil backed type laminate when piggybacking a Tedlar printed laminate over an existing laminate.

safety factor of 25 must meet the pass/fail criteria of a 4-minute smoke density (D_s) maximum of 200.

INTERIOR PANEL REPAIR.

As previously discussed, renovation and refurbishment of aircraft interiors has become a viable option to full interior replacement for many airlines as a considerable cost savings can be realized. When this type of work is performed on an aircraft's interior sidewall, ceiling, and stowage bin panels, it is often accompanied by various forms of repair work as well. Normal wear and tear to the interior panels can result in dents, punctures, holes, and cracks in these areas, many times necessitating replacement. In most cases, however, the cabin interior damage can still be repaired for less than the cost of a replacement panel. From a regulatory standpoint, however, current FAR's do not specifically address the issues of repair to interior material systems. What constitutes a repair? When is it necessary to conduct certification tests on repaired interior systems? More importantly, *how* are certification tests performed on repaired material systems? These are the types of questions that have been raised through the work of the subgroup, and it is important that they be addressed in order to allow for consistent certification procedures as repairs to interior material systems are becoming increasingly widespread.

The most common type of repair made to flat panel surfaces of an aircraft interior involves the use of plastic-based (polyester) *fillers* or filling compounds. Fillers come in a variety of consistencies, each designed to perform a specific task. There are spray and brush type fillers which are very light and can actually be sprayed onto panels to repair minor surface scratches and imperfections. These fillers are generally used on interior panels to prep them prior to being painted or decorative laminated so that a smooth, finished surface can be obtained. There are also spatula or putty type fillers which are much more dense than the spray fillers and are typically used for the repair of more extensive damage such as cracks, dents, and holes. During the first subgroup meeting, the issue of filler use was brought up, and participants inquired into the applicability of the small parts exclusion (Appendix F, part I (a)(1)(v)). This exclusion addresses the many small parts within an aircraft cabin, such as knobs, handles, rollers, fasteners, clips, grommets, rub strips, pulleys, and small electrical parts. According to the rule these parts are exempt from fire testing on the basis that they would not significantly contribute to the propagation of a fire. At the first meeting there was consensus among many subgroup members that small repairs made to flat panels should fall under this category and thereby be exempt from certification testing. The subgroup also cited the "144-square-inch rule," which is an unwritten procedure that is followed by many certification offices which allows for the exemption of fire testing of interior panels of less than one square foot in area (this procedure is loosely interpreted, therefore several panels which are less than one square foot in area but within close proximity of one another *would* require testing).

While it is questionable that the use of *a very small amount* of filler (even the most flammable type) would render an aircraft cabin more flammable than a cabin without any filler, there must be a method of regulating its use. It is pointless to implement upgraded flammability standards regarding flat panels and at the same time permit the widespread use of potentially flammable filler materials. This might not seem significant if a filler was confined to a singular panel, but what

about when the entire interior is treated with a thin layered filler application, for example? It is possible that the fine layer, when used throughout the entire cabin, could significantly raise the heat release rate of the interior. It is also possible that an area of high wear or likely damage (e.g., from galley carts) could accumulate an extensive amount of spatula filler over a period of time, causing a marked increase in the flammability of the panels. This being the case, there are only two possible solutions to insure these situations do not occur: (1) limit the amount/size of the repairs, thus limiting the amount of flammable material entering the cabin, or (2) simply establish a pass/fail criteria for the repair procedure itself. Since the airlines do not have an accounting system to track the size/types of repairs that are made using fillers, the only feasible method of regulation would be to establish pass/fail criteria on the repair procedure itself. A detailed discussion of the filler test method evolution and the subgroup's recommended procedure for testing fillers is described in the Test Results section.

CARGO COMPARTMENT LINER REPAIR.

When a rip, tear, or puncture of a cargo liner occurs, it is either replaced or, more often, repaired if the damage is not too severe. Repairs generally consist of patches of similar material bonded to the existing cargo liner with an epoxy type adhesive (another method of attachment is to mechanically bond a similar section of cargo liner to the existing liner using rivets). This repair area is then coated with an intumescent paint to resist heat, preventing separation in the event of a fire.[3] In order for this type of repair system to qualify for certification, it currently must pass a two-part test. First, the material which comprises the fire barrier (the patch) must be tested as a flat sheet, measuring 16 by 24 in., in the ceiling position of the 2-gallon-per-hour cargo liner test apparatus. In this position, the material must resist flame penetration for 5 minutes, and the temperature at the backface of the material, 4 inches above the surface, must not exceed 400°F at any time during the 5-minute test. Additionally, the patch system must be tested for adhesion. This is done by attaching a 4- by 4-in. patch to another 16- by 24-in. liner specimen and again placing the system in the ceiling position of the cargo liner test rig. In order to pass the test, the patch must remain adhered for the entire 5-minute test.

Several areas of concern were discussed with regard to the testing of cargo liner patches. Two subgroup members with extensive experience in the field of cargo liner repair and testing felt that the adhesion portion of the repair test was inadequate and too vague. The following paragraphs describe the suggested additional measures that should be followed when testing a patching system for adhesion.

DAMAGE AREA. The first topic discussed was the lack of a standardized damage area under the 4- by 4-in. patch. The subgroup participants argued that patches are generally used in conjunction with fiberglass liners, which typically rip along two axis in perpendicular directions from the point of puncture causing an L-shaped damage area. According to the participants, the amount of area that the patch adheres to is critical, and the qualification procedure can be misleading if the 4- by 4-in. patch is simply placed over the test cargo liner with no more than a

[3] The Boeing Company also offers several cargo liner tapes, qualified to BMS 5-146, that are suitable for this purpose. These tapes are 3M YR-367 FR, Permacel P-212HD, and Permacel P-621.

slit in it to simulate damage. This could result in the patch passing the qualification test, but failing catastrophically in service when placed over an L-shaped damage area in which the patch would have a much lower surface area to adhere to. In order to make the adhesion test more realistic, the subgroup agreed that a 5- by 5- by 1-in. wide L-shaped void (figure 3) or other suitable void should be removed from the liner, and an 8- by 8-in. patch should be tested for adhesion over this void instead of the 4- by 4-in. patch over no void (current method).

LINER TYPE/THICKNESS. In addition to the requirement that the patch be tested for adhesion on the exact type of liner that it is intended to be used on in service, the subgroup felt that there should also be a requirement that the patch be tested for adhesion on the exact *thickness* as well. A certain thickness liner may react quite differently than another when exposed to heat and flames because of the difference in resin content. The thicker the liners, the more significant is the release of heat due to the additional amount of resin. Conversely, thinner liners contain less fiberglass reinforcement, thereby providing less structural support for the patch to remain adhered to. These factors may allow a patch to pass the test on a given thickness of liner, but ultimately fail in service on a different thickness of liner. As an alternate, a patch can be tested on a minimum and maximum liner thickness, eliminating excessive testing on all thicknesses in between.

PATCH OVERLAP. The amount of patch overlap beyond the actual damaged area of the liner is equally critical in insuring that the patch remains properly attached. The manufacturer must adequately specify this information so that repairs made in areas near edges or corners have sufficient overlap to prevent patch failure. If, for example, a particular patch requires a minimum of 2 inches overlap, then it could not be used for repairs that are less than 2 inches from a corner or seam, and the liner would have to be replaced in this case.

SHINGLING. The most common form of damage that cargo liners experience are rips, tears, and punctures. In some instances, the rips and tears may be of considerable length, rendering a single patch inadequate to fully cover the damage. When this type of damage is encountered, the only feasible method of repair is to shingle several patches over each other to accommodate the damage length. If a patch is intended for this type of use, it must exhibit the ability to remain adhered to itself during the adhesion test. One method of performing this test would be to take two 4- by 4-in. patches and overlap them in the center of the cargo liner; the width of overlap would be representative of the in-service overlap, as specified by the manufacturer (figure 4).

SOFT LINERS. The testing of neoprene coated fabric liner repairs, or soft liner repairs was also discussed at earlier meetings. These types of liners are typically used as partition separators, or control panel covers. Repairs made on these types of liners generally consist of a patch of identical material stitched to the liner using Teflon or fiberglass thread. In order to qualify a repair of this type, the above guidelines should be followed as well.

TEST RESULTS

INITIAL FILLER TESTING.

After the second subgroup meeting, most participants were in agreement that some initial tests should be run in both the NBS smoke chamber and the OSU rate of heat release apparatus to determine typical smoke production numbers and heat release rates of a variety of currently available fillers. Due to logistics problems, the initial tests utilized only one filler system which was designed specifically for the aerospace industry, in addition to two polyester-based automotive type fillers (it was initially believed that one of the major airframe manufacturers used automotive filler in one of its finishing processes, but subsequent meetings found this to be untrue. This manufacturer does, however, use a polyester-based filler very similar to the automotive fillers tested). The three fillers were tested in conjunction with several interior panels donated by two companies, a panel manufacturer and an airline, both of which have employees active in the subgroup. The panels consisted of a Schneller crush core, two honeycomb types manufactured by Jamco (JMS 0408-30-89 and JMS 0402-127-1), and another honeycomb manufactured by Ciba Geigy. During these initial tests, the test panels had square areas removed from their centers, simulating damage. These areas were filled with the three different fillers and finish sanded with #400 sandpaper. All finished test panels had a skin coat of filler, approximately 0.020 in. thick, over the entire surface area of the panels. The simulated damage area that was removed from the center of the panels measured 2 by 2 in. on the OSU samples, and 1 by 1 in. on the NBS smoke chamber test panels, the entire thickness of the panels. The test samples were set up this way so that the same percentage of surface area of both the 3- by 3-in. and 6- by 6-in. panels were filled (i.e., 1 to 9 ratio of filled area to total area of the panel; 1 square inch on the 9 square inch 3- by 3-in. panel, and 4 square inches on the 36 square inch 6- by 6-in. panel)[4]. The test panels were also weighed before and after the filling procedures so that a filler weight could be calculated. The results of all the OSU tests are tabulated in figures 5, 6, and 7. The three major findings of these initial tests were (1) the polyester based automotive fillers produced high total and peak heat release rates regardless of the type of substrate it was applied to, (2) the thickness of the two polyester based automotive fillers had a direct impact on the peak heat release rate and total heat release. In a majority of the sets of panels tested, the panel with the most filler weight (and hence, thickness of filler over the substrate surface) produced the highest peak heat release rate and total heat release, and (3) there was at least one filler product currently available which met this modified OSU filler test.

The results of the NBS tests are tabulated in figures 8, 9, and 10. As shown, most of the samples are well below the 4-minute D_s level of 200. Although the polyester-based fillers produced elevated peak and total heat release, they didn't produce much smoke, yielding D_s numbers much lower than the filler designed for aerospace use. Similar to the heat release tests, the test samples with the highest filler weight yielded the highest smoke production.

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[4] Although the original plan was to use a 1- by 1-in. square void, it was much easier to drill a 1-in diameter hole in the smaller panels. Because the area of the circular hole was very close to that of the square hole, the differences were assumed negligible.

SPATULA FILLER TESTS USING STAINLESS STEEL PLATES.

The initial tests were a good starting point in order to gain some background information on the characteristics of the various fillers, but a test needed to be devised which could better decipher between these materials. Even though the fillers which consistently yielded the highest heat release rates did so regardless of the type of substrate they were used over, there needed to be a more standardized method for testing fillers in order to eliminate any potential synergistic effects that could exist between the fillers and the panels. The only feasible method for obtaining information on individual filler performance was to isolate them, so that data would reflect the heat release rate of the filler only, irrespective of the type of substrate it was applied to (this approach was also taken since it would be very time consuming to test all of the hundreds of substrate/filler combinations). This was accomplished by constructing special stainless steel sample plates with various diameter holes cut in the center, which could be filled with filler and tested in the OSU apparatus. Since the stainless steel would not combust during the test, it would not contribute to the heat release rate of the filler, allowing more accurate results. Three different fillers were tested in filler holders of 0.125 and 0.250 in. thickness, with hole sizes of 2, 3, and 4 in. diameters. As shown in figure 11, a 2-in.-diameter hole yields very low peak and total heat release numbers due to the heat sink effect of the large surface area of stainless steel. By enlarging the hole to 3 in., the heat sink effect diminished somewhat as indicated by an increase in the peak and total heat release of the fillers (figure 12). The increase in heat output is actually due to the reduced heat sink effect of the metal and the proportionate increase in the surface area of the flammable filler. As expected, an increase to 4-in.-diameter holes resulted in even higher numbers (figure 13). It became apparent from these tests that the most accurate method for evaluating the heat release output of a filler would be to eliminate the heat sink effect of the steel altogether by testing a full 6- by 6-in. slab of the filler material. In order to perform this test, 6- by 6-in. pans were constructed of 26 gauge steel, in depths of 0.125 and 0.250 in. Although these filler tests yielded the highest output, the results were still inconsistent, as shown if figure 14. With two of the fillers, the peak heat release rate was actually lower during the 0.250-in. test than with the 0.125-in. test, and with one filler the total heat release was also much lower during the test using a greater thickness. Due to a limited supply of the various fillers, only one test could be conducted with each thickness of filler; it is difficult to draw conclusions from such a small number of tests and thus apparent that further tests using this format would be necessary. Inconsistencies in the results of the filler pan tests could be attributed to the heat sink effect of the materials themselves (i.e., the reason the thicker filler produced lower numbers in some cases) or from general test fluctuations.

SPATULA FILLER ONLY TESTS.

After the results of the spatula filler tests in the stainless steel plates and the filler pan tests were reported to the working group, it was agreed that further tests should be conducted using the filler-only testing format. To accommodate this, tests were conducted at the FAA Technical Center in which special Teflon molds were used to produce slabs of filler in 0.125 and 0.250 in. thickness (figure 15). The spatula filler could be applied to the mold, smoothed down to the appropriate thickness by raking away the excess filler, and allowed to dry. Once the filler hardened, the borders of the mold could be removed, and the sample could easily be popped out

due to the nonstick ability of the Teflon surfaces. This allowed test samples to be manufactured exclusively of filler, without the intrusion of a metal pan or other heat sink. Five different types of fillers were tested; all of which were designed for the aerospace industry. Of the five fillers, two had previously been tested using the other methods (i.e., over different panel substrates, and with stainless steel holders plates). The results of the spatula filler-only tests are tabulated in figures 16 and 17. As shown, four of the five fillers would pass the test if the acceptance criteria were 100/100. Most of the fillers yield numbers close to this level, with one filler displaying slightly lower peak and total heat release than the others (80.3/76.8 in a 0.125 in. thickness and 68.5/73.4 in a 0.250 in. thickness). As was the case with the filler pan tests, a majority of the fillers displayed lower total heat release when tested in greater thicknesses, due to the heat sink effect of the material. Another finding, also displayed during earlier tests, was the high level of smoke production of several fillers.

CONCLUSIONS

In conclusion, the subgroup focused on problems specific to three areas: (1) cargo liner repair and the need for additional test criteria to the currently accepted qualification method, (2) renovation of in-service interior material systems and the associated problems with certification in the absence of original base panel material, and (3) repair of in-service interior panels, the use of plastic-based fillers, and the development of a test method for qualification of fillers.

In terms of repair to cargo compartment liners, most of the research and testing was already complete as several group participants had extensive experience in this area. The subgroup investigated the weaknesses of the currently accepted test method and recommended additional measures based on laboratory test results (see Cargo Compartment Liner Repair in the Discussion section). These additional measures will produce a more realistic test and ensure that a patch will not fail in service by becoming separated from the liner.

Extensive test work was not required during the establishment of recommended certification testing criteria for renovated interior systems. Most of the work involved a review of current practices and procedures, discussion with repair facilities, as well as discussion/confirmation with the certification offices. The recommended method for conducting certification tests on renovated (i.e., relaminated or repainted) interior panels is based on a straightforward approach, which focuses on minimizing the amount of testing, while ensuring that only acceptably renovated systems will result. According to the current FAR's, any and all renovated interior material systems must continue to meet the requirements of the type certification basis of the aircraft. The only method for making an absolute determination that the renovated material system is in compliance is to run a sample test in the OSU chamber (and NBS, if 65/65/200); the sample must reflect exactly the panel construction to be used in the aircraft (i.e., base panel with decorative laminate or paint). In the event that sufficient quantities of the base panels are not available, a reasonable and relatively cost-efficient method proposed for closely approximating the heat release characteristics of the renovated panel is to use three sets of representative surrogate panels of similar construction and material type. Of the three tests using the surrogates (average of two tests per panel type), the configuration with the highest output should be taken as the initial test

value. A safety factor[5] of 5/5 should be added to this to account for synergistic effects, yielding a final value which must meet either 65/65 or 100/100. At the time of this report writing, tests were being conducted to determine the accuracy of this proposed method. A quantity of two different in-service ceiling panels which met the 65/65/200 requirements had been acquired; these panels were to be renovated using a new decorative on one panel and a paint procedure on the other. In conjunction with this, surrogate panels would be constructed to resemble each of these panels, and then identically renovated. A comparison could then be made of the heat release of the in-service panel versus the surrogate panels to determine the accuracy of using surrogates as predictors of the heat release of altered in-service materials. Similar tests will follow to determine the accuracy of the surrogates to predict smoke output.

In addition to surrogate use, several operators had expressed concern over interior panel painting when making renovations. More specifically, they stated that during certain painting procedures the thickness of the paint can often vary several 10's of microns, resulting in fluctuations of the OSU test results. The operators were concerned that a certification test could be passed using a particular thickness of paint, but a follow-up test performed at the request of the aviation authority could reveal that the actual in-service painted panels are not in compliance, the result of a thicker paint layer. The operators felt that an incident such as this would necessitate costly procedures to remove these panels and other similarly finished units. Although these concerns were more of a quality control/procedural issue than a renovation issue, they were discussed nonetheless. The best recommendation the subgroup could offer was to run tests on a variety of paint thicknesses, determine what the worst case would be (usually the thickest amount of paint), and implement measures to ensure that this thickness is not exceeded at any time during interior overhaul/renovation. Since it is often not feasible for an ACO/DER to witness OSU tests after each and every painting procedure, these types of safeguards should be implemented and adhered to by the operators themselves since it is ultimately their responsibility to maintain compliance. An operator could, for example, run tests with several simulated "paint jobs" over an interior panel test specimen (a "job" consisting of several layers of paint each). If the operator determines that after the third job the ***highest*** HRT/PHRR of ***any*** of the interior panels is 63/63 and after the fourth job it is 66/66, the operator should then make note of this and refrain from making any painting renovations after the third paint job. This same approach could be used when making renovations consisting of "piggybacked" laminates.

Repair of interior systems using plastic-based fillers was another consideration as numerous tests were conducted in the OSU and NBS chambers to develop background data. As discussed, there were two potential solutions being investigated for certifying fillers used in panel repair. A questionnaire was sent to 40 group participants in order to receive additional feedback on this subject matter as it was often difficult to address all the problems associated with the testing of

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[5] A safety factor of 5/5 would effectively reduce the allowable heat release output to 60/60 in many cases. The intent of the 5/5 safety factor was to account for any synergistic effects that may develop between materials since the surrogate materials being used to run the certification tests closely resemble the in-service materials but are not exact replacements. It is ultimately the responsibility of the repair facility to produce a material system which maintains compliance; if the repair facility is confident that their renovation scheme will react identically on the in-service materials as it would with the surrogates, they have justification for eliminating the safety factor.

fillers at subgroup meetings. There were only a few responses to the questionnaire, but those received were very helpful.

Based on the results of the spatula filler-only tests as well as the responses to the questionnaire, the subgroup initially recommended that several guidelines be followed for the certification of repairs made using plastic-based fillers. The guidelines were actually a unification of the two methods that were being discussed, rather than a selection of one method over another. Since the "144-square-inch rule" is a generally accepted practice, subgroup members thought it seemed reasonable that any surfaces larger than this could be tested in the *system format*. Spray and brush fillers are used extensively for the smoothing of surface imperfections, scratches, porosity, etc., and are typically applied over large surface areas in very thin layers (certain spatula type fillers are also used over large surface areas in very thin layers). The panel surfaces are then painted or decorative laminates are installed over top of the fillers during the final procedure yielding the finished product. Since these types of fillers are applied in very thin layers, it is reasonable to conduct a certification test by building a typical test panel using a substrate and a representative layer(s) of the filler, followed by the decorative or the paint. The entire assembly would then be required to pass 65/65 or 100/100 depending on the type certification basis of the aircraft. As is the case during the renovation certification test procedures, if test specimen substrates identical to the in-service panels are unavailable, three sets of surrogate panels can be used according to the method described previously.

Repairs made to panel surfaces using spatula/putty fillers are generally for more extensive damage but are usually confined to smaller surface areas. The subgroup consensus was that damage areas which are relatively large would require panel replacement and would not likely be repaired with large quantities of spatula type fillers. For this reason, it was initially recommended that repairs of less than 144 square inches be tested in the *spatula filler-only format*. As discussed, filler tests have been conducted using this format in thicknesses of 0.125 and 0.250 in. with a majority of the fillers yielding peak and total heat release rates of approximately 80 to 100. In an effort to screen out only the worst fillers, it was recommended that the peak and total heat release be no greater than 100/100 when tested in thicknesses of 0.125 and 0.250 in. This pass/fail criteria was based on the best available materials at the time of this report writing. It is possible that at some future point the pass/fail criteria could be lowered to reflect newer, lower heat release fillers as they become available.

After further consideration of the above mentioned proposals regarding renovation and repair, the subgroup recommended several changes be implemented. Since most renovation procedures which take place at an aircraft overhaul facility also involve the concurrent repair of damaged panels, it seemed more reasonable to combine these two procedures. In doing so, the entire recommended procedure for conducting heat release recertification tests for altered in-service materials became somewhat simplified. If a renovation, repair, or alteration of an in-service interior system is performed and this alteration is determined to be large enough in surface area to require a heat release recertification test by the appropriate authority, it should be performed in the system format as described above. Although there are many exceptions which exist whereby insignificant amounts of certain cabin materials may be exempt from heat release testing (e.g., the small parts exclusion and the 144-square-inch rule), these exceptions apply to new material

systems only and do not apply to in-service materials which are altered. However, the applicability of additional heat release testing of many of the small repairs made to interior panels is open to interpretation and in many cases is not required. For this reason, if the alteration can be classified as a simple repair using a plastic-based filler for repair of a crack, dent, hole, scratch, etc. and is sufficiently small in surface area (as deemed by the appropriate authority) to be exempt from a system format heat release re-certification test, then it is recommended that the filler at least meet the requirements of the spatula filler only test format as described above.

As mentioned previously, renovation and repair of aircraft interiors has become more widespread with the domestic airlines' average fleet age steadily increasing. Although renovations and repairs made to the interior materials have become more common, it is still the airlines' ultimate responsibility to ensure that the cabin materials remain in compliance with the aircraft's type certification basis. Although the carriers may view the subgroup's recommendations as an additional regulatory burden, they are a necessity. The aircraft that are in use today were delivered to the airlines equipped with low heat release/smoke interiors (post 1990), and it is the responsibility of the operator of the aircraft to insure that any alterations to the cabin materials result in systems that remain in compliance. Although most operators are severely time constrained in terms of aircraft downtime, it is advisable that they maintain an adequate supply of materials to run certification tests with and to conduct the necessary laboratory tests prior to making renovations and/or repairs (according to the above guidelines) to alleviate any problems ahead of time. If the materials needed to run the certification tests are not available, there are other methods of conducting these certification tests using surrogates as described in this report.

Due to the destructive nature of the OSU and NBS tests, it is not possible for an FAA ACO to remove an aircraft's sidewall panel or stowage bin door and make a determination as to whether or not it is within compliance. It is possible, however, that materials for testing can be retrieved from aircraft that have been involved in accidents. This type of follow-up testing has been performed in several cases recently resulting in questions and concerns over the continued compliance of materials in older aircraft. Accidents which result in fatalities due to the burning of interior materials could expose the operators to litigation, particularly in the event that materials are found to be noncompliant as a result of renovations or repairs.

The recommendations of this subgroup are aimed at insuring a fire safe aircraft cabin after renovations/repairs have been made and not intended to place an undue burden on the operators and airframe manufacturers. The procedures and guidelines in this report were developed taking into account the daily operations of the airline industry and the need to maintain safety. It is the intent of the Working Group that these guidelines be included in the Aircraft Materials Fire Test Handbook, which in turn will become the primary referenced document in an FAA advisory circular on flammability. It must be emphasized that the procedures described herein are *recommended* and not required as of yet. If an operator decides not to run tests after making renovations or repairs, he runs the risk of producing a material system which is not in compliance. By following the recommended procedures, however, the operator can be certain that the renovations will result in compliant material systems.

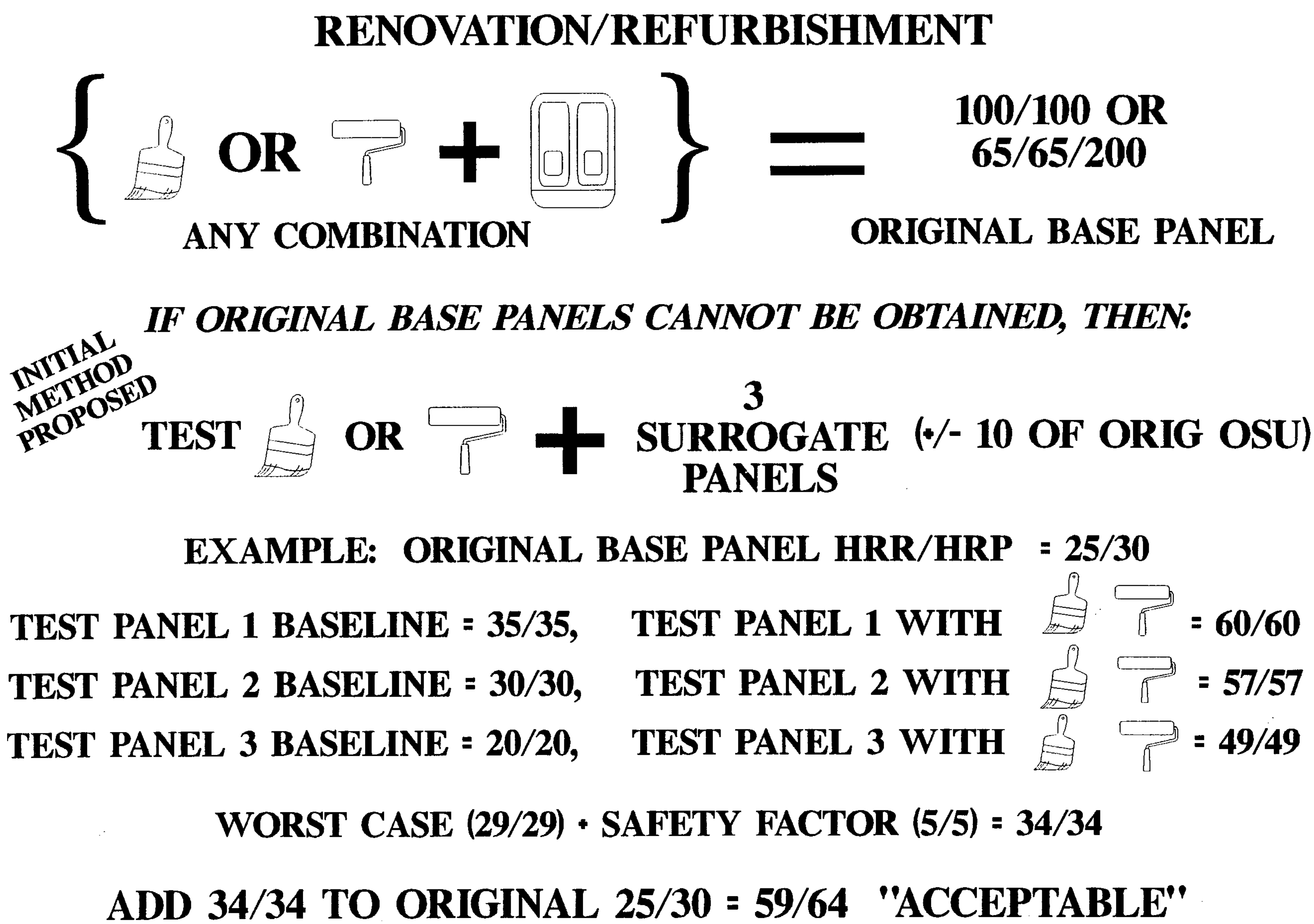


FIGURE 1. INITIAL METHOD PROPOSED FOR TESTING RENOVATED INTERIOR PANELS

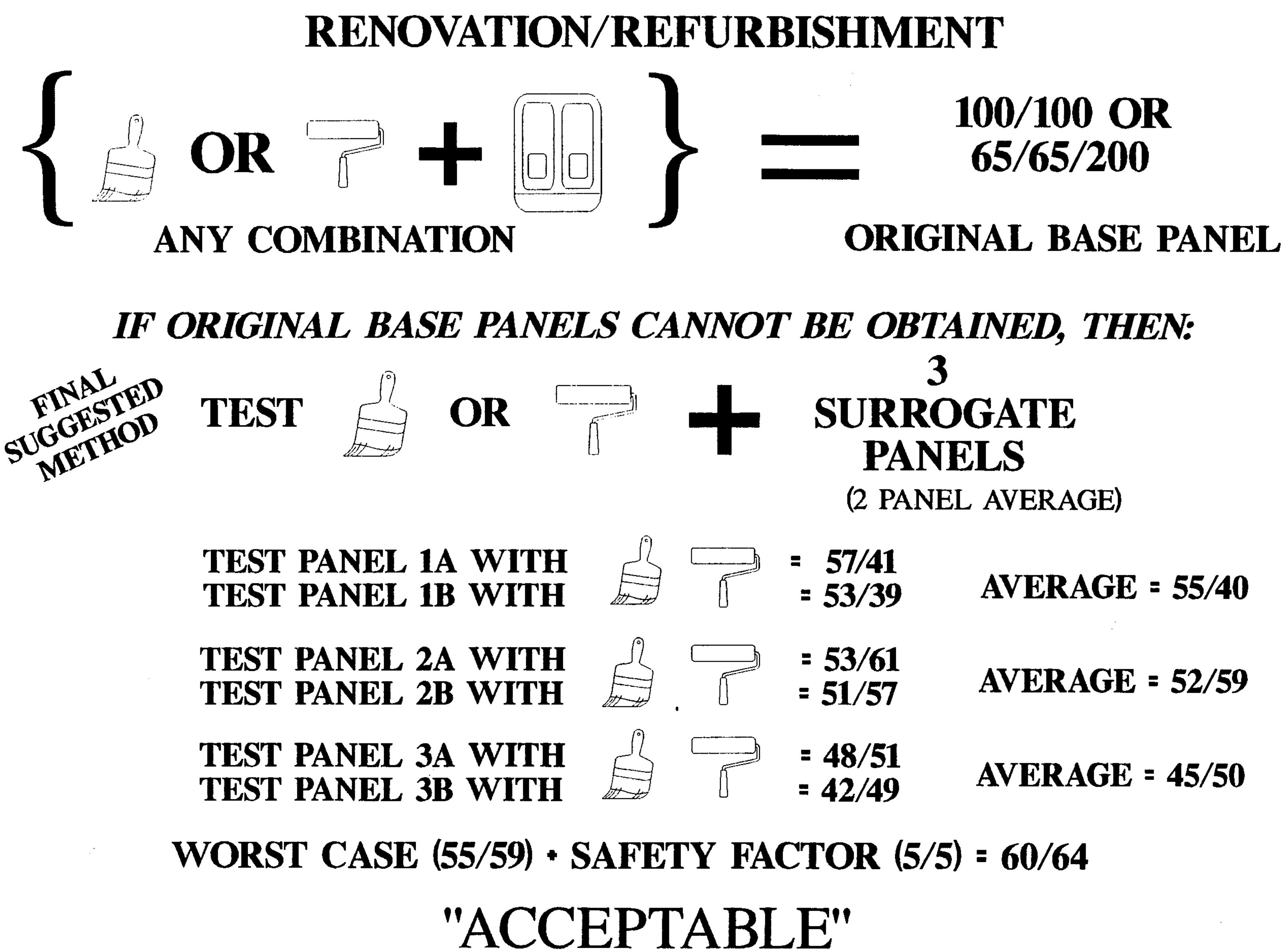


FIGURE 2. FINAL METHOD PROPOSED FOR TESTING RENOVATED INTERIOR PANELS

8- by 8-INCH PATCH OVER STANDARD DAMAGE

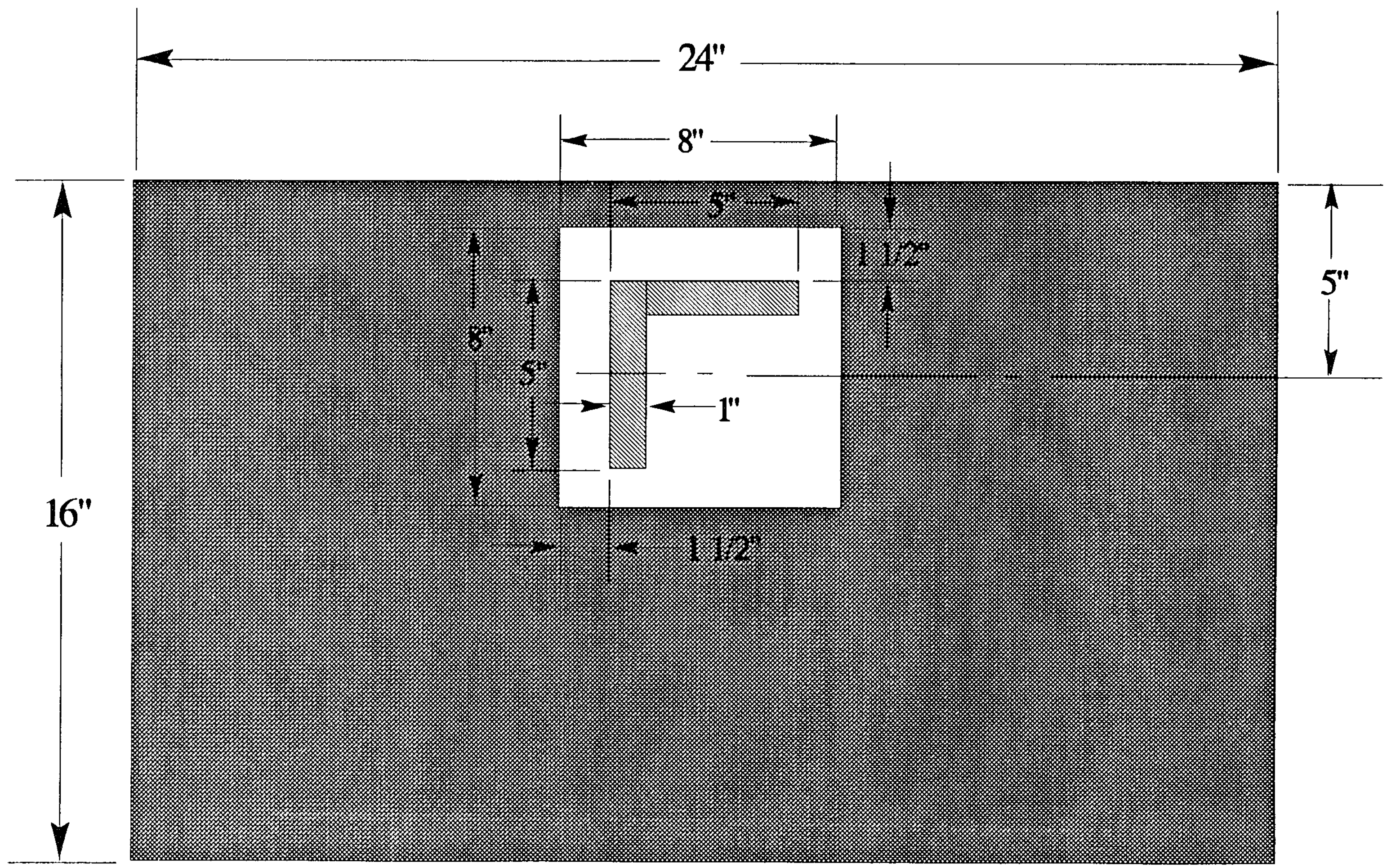


FIGURE 3. CARGO LINER PATCH ADHESION TEST

OVERLAPPED PATCHES FOR SHINGLING TEST

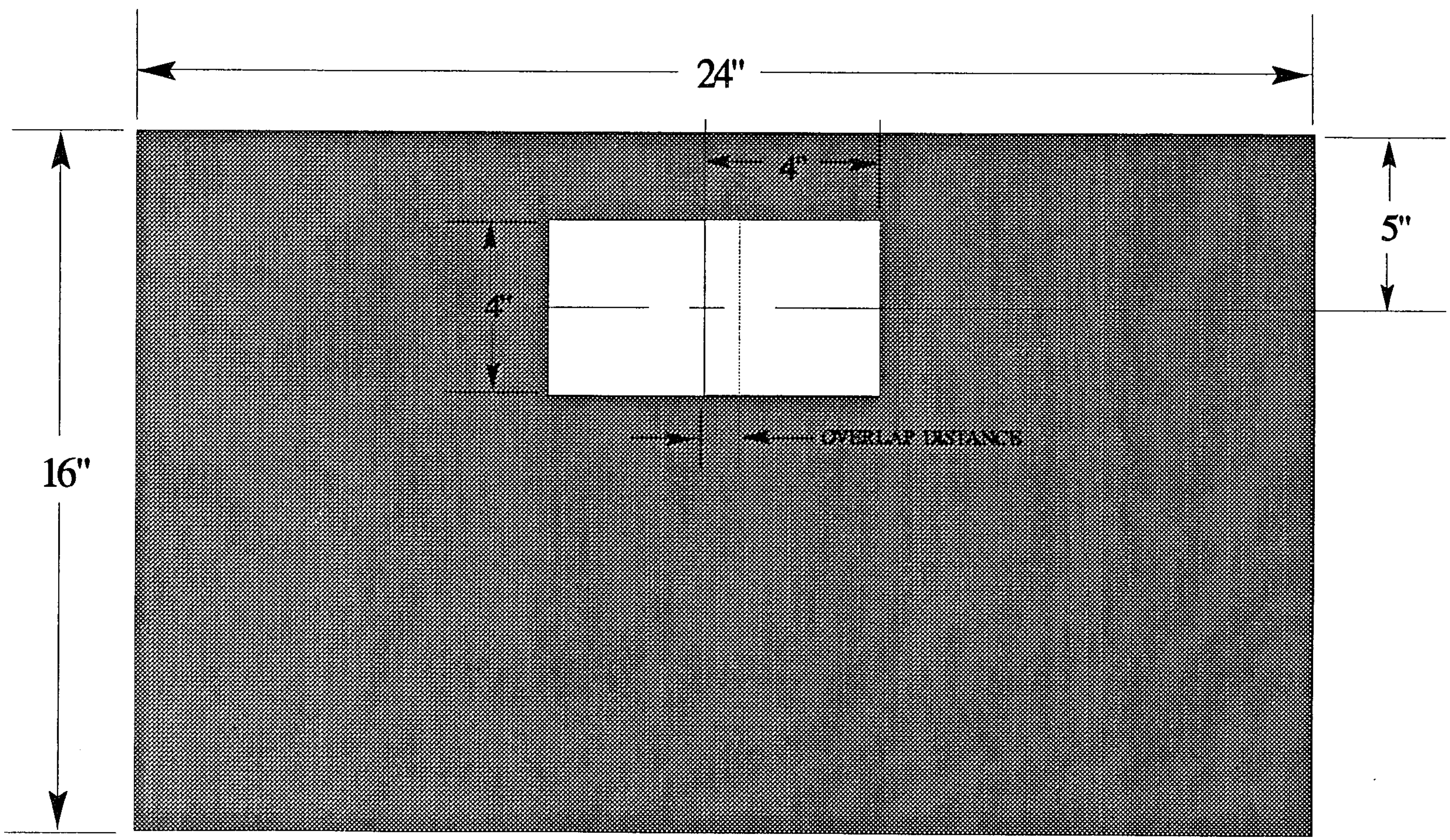


FIGURE 4. CARGO LINER PATCH SHINGLING TEST

OSU TESTS USING "BONDO" AUTOMOTIVE BODY FILLER

Panel/Filler/Test	Panel Weight (g)	Filler Weight(g)	Panel + Filler Weight(g)	Heat Release Total kW-min/m^2	Peak Heat Release Rate kW/m^2
A/X1	22.8	30.4	53.2	120.1	114.0
A/X2	22.6	31.1	53.7	126.7	116.7
A/X3	23.0	37.0	60.0	*129.0*	*122.6* *****
A/X4	22.8	22.3	45.1	X	X
			FILLED PANEL AVERAGE	**125.3**	**117.8**
			BASELINE PANEL 1	44.09	55.64
			BASELINE PANEL 2	42.89	51.03
			AVERAGE	**43.49**	**53.34**
B/X1	22.8	27.0	49.8	111.4	82.19
B/X2	22.5	25.7	48.2	113.5	84.24
B/X3	21.8	26.7	48.5	X	X
B/X4	22.1	26.2	48.3	X	X
			FILLED PANEL AVERAGE	**112.5**	**83.22**
			BASELINE PANEL AVERAGE	**43.49**	**53.34**
C/X1	27.4	51.4	78.8	89.94	113.3
C/X2	25.5	*62.4*	87.9	*126.0*	*133.9* *****
C/X3	25.5	47.5	73.0	89.52	99.05
C/X4	25.5	58.4	83.9	X	X
			FILLED PANEL AVERAGE	**101.8**	**115.4**
			BASELINE PANEL 1	28.35	21.34
			BASELINE PANEL 2	23.09	19.81
			AVERAGE	**25.72**	**20.58**
D/X1	47.6	63.5	111.1	126.2	161.6
D/X2	47.8	*67.4*	115.2	*149.1*	*151.6* *****
D/X3	48.2	53.4	101.6	96.37	106.1
D/X4	47.0	55.4	102.4	X	X
			FILLED PANEL AVERAGE	**123.9**	**139.6**
			BASELINE PANEL 1	47.64	41.60
			BASELINE PANEL 2	43.47	34.40
			AVERAGE	**45.56**	**38.00**
E/X1	52.9	*58.4*	111.3	*131.8*	*137.8* *****
E/X2	52.8	52.1	104.9	121.6	131.3
E/X3	51.5	53.2	104.7	129.2	138.
E/X4	51.9	58.1	110.0	X	X
			FILLED PANEL AVERAGE	**127.5**	**135.8**
			BASELINE PANEL 1	50.56	48.96
			BASELINE PANEL 2	60.32	44.34
			AVERAGE	**55.44**	**46.65**

X not tested

PANEL A: SCHNELLER CRUSH CORE
PANEL B: SCHNELLER CRUSH CORE (one-week cure time of filler)
PANEL C: JAMCO HONEYCOMB (JMS 0408-30-89)
PANEL D: JAMCO HONEYCOMB (JMS0402-127-1)
PANEL E: CIBA GEIGY HONEYCOMB (KLM 261161)

FILLER X: BONDO AUTOMOTIVE FILLER
FILLER Y: HSH AEROSPACE
FILLER Z: MARTIN SENYOUR AUTOMOTIVE FILLER

FIGURE 5. EARLY SUBSTRATE/SPATULA FILLER TESTS IN OSU CHAMBER

OSU TESTS USING HSH AEROSPACE FILLER

Panel/Filler/Test	Panel Weight (g)	Filler Weight (g)	Panel + Filler Weight (g)	Heat Release Total kW-min/m²	Peak Heat Release Rate kW/m²
A/Y1	22.8	35.1	57.9	73.14	60.54
A/Y2	22.7	36.1	58.8	62.72	55.20
A/Y3	22.8	37.4	60.2	65.43	55.97
A/Y4	22.8	35.5	58.7	X	X
			FILLED PANEL AVERAGE	**67.10**	**57.24**
			BASELINE PANEL 1	44.09	55.64
			BASELINE PANEL 2	42.89	51.03
			AVERAGE	**43.49**	**53.34**
B/Y1	22.6	34.5	57.5	76.23	85.45
B/Y2	22.2	35.2	57.4	78.16	73.00
B/Y3	22.8	32.4	55.2	X	X
			FILLED PANEL AVERAGE	**77.20**	**79.23**
			BASELINE PANEL AVERAGE	**43.49**	**53.34**
C/Y1	25.6	50.8	76.4	53.28	68.24
C/Y2	25.4	53.3	78.7	53.49	79.73
C/Y3	27.5	52.8	80.3	46.45	55.61
C/Y4	25.5	56.5	82.0	X	X
			FILLED PANEL AVERAGE	**51.07**	**67.86**
			BASELINE PANEL 1	28.35	21.34
			BASELINE PANEL 2	23.09	19.81
			AVERAGE	**25.72**	**20.58**
D/Y1	47.7	53.4	101.1	71.02	55.63
D/Y2	48.0	55.0	103.0	72.16	56.16
D/Y3	47.9	56.5	104.4	60.61	51.17
D/Y4	48.1	56.2	104.3	X	X
			FILLED PANEL AVERAGE	**67.78**	**54.32**
			BASELINE PANEL 1	47.64	41.60
			BASELINE PANEL 2	43.47	34.40
			AVERAGE	**45.56**	**38.00**
E/Y1	52.1	55.6	107.7	84.15	56.63
E/Y2	52.2	54.5	106.7	87.29	50.69
E/Y3	53.0	56.1	109.1	77.21	53.15
E/Y4	52.0	56.2	108.2	X	X
			FILLED PANEL AVERAGE	**82.88**	**53.49**
			BASELINE PANEL 1	50.56	48.96
			BASELINE PANEL 2	60.32	44.34
			AVERAGE	**55.44**	**46.65**

X not tested

PANEL A: SCHNELLER CRUSH CORE
PANEL B: SCHNELLER CRUSH CORE (one-week cure time of filler)
PANEL C: JAMCO HONEYCOMB (JMS 0408-30-89)
PANEL D: JAMCO HONEYCOMB (JMS 0402-127-1)
PANEL E: CIBA GEIGY HONEYCOMB (KLM 261161)

FILLER X: BONDO AUTOMOTIVE FILLER
FILLER Y: HSH AEROSPACE
FILLER Z: MARTIN SENYOUR AUTOMOTIVE FILLER

FIGURE 6. EARLY SUBSTRATE/SPATULA FILLER TESTS IN OSU CHAMBER

OSU TESTS USING MARTIN SENYOUR AUTOMOTIVE BODY FILLER

Panel/Filler/Test	Panel Weight (g)	Filler Weight (g)	Panel + Filler Weight (g)	Heat Release Total kW-min/m^2	Peak Heat Release Rate kW/m^2
A/Z1	22.4	18.7	41.1	106.7	82.50
A/Z2	22.6	20.9	43.5	108.0	69.11
A/Z3	22.5	18.3	40.8	113.1	74.92
A/Z4	22.7	23.3	46.0	X	X
		FILLED PANEL AVERAGE		**109.3**	**75.51**
		BASELINE PANEL 1		44.09	55.64
		BASELINE PANEL 2		42.89	51.03
		AVERAGE		**43.49**	**53.34**
B/Z1	22.4	28.0	50.4	125.6	98.74
B/Z2	22.3	*42.4*	64.7	*135.6*	*131.8* *****
B/Z3	22.6	29.2	51.8	130.3	105.5
B/Z4	22.2	46.5	68.7	X	X
		FILLED PANEL AVERAGE		**130.5**	**112.0**
		BASELINE PANEL AVERAGE		**43.49**	**53.34**
C/Z1	25.6	38.7	64.3	60.59	78.55
C/Z2	25.6	48.3	73.9	84.54	82.48
C/Z3	25.5	42.7	68.2	71.61	91.71
		FILLED PANEL AVERAGE		**72.25**	**84.25**
		BASELINE PANEL 1		28.35	21.34
		BASELINE PANEL 2		23.09	19.81
		AVERAGE		**25.72**	**20.58**
D/Z1	48.0	43.1	91.1	76.17	97.35
D/Z2	47.3	*46.9*	94.2	*81.97*	*112.8* *****
D/Z3	48.0	42.4	90.4	78.06	95.30
		FILLED PANEL AVERAGE		**78.73**	**101.8**
		BASELINE PANEL 1		47.64	41.60
		BASELINE PANEL 2		43.47	34.40
		AVERAGE		**45.56**	**38.00**
E/Z1	52.3	41.9	94.2	86.10	96.04
E/Z2	52.5	*43.5*	96.0	*100.1*	*113.6* *****
E/Z3	52.7	39.5	92.2	94.85	86.34
E/Z4	51.8	44.0	95.8	X	X
		FILLED PANEL AVERAGE		**93.68**	**98.66**
		BASELINE PANEL 1		50.56	48.96
		BASELINE PANEL 2		60.32	44.34
		AVERAGE		**55.44**	**46.65**

X not tested

PANEL A: SCHNELLER CRUSH CORE
PANEL B: SCHNELLER CRUSH CORE (one-week cure time on filler)
PANEL C: JAMCO HONEYCOMB (JMS 0408-30-89)
PANEL D: JAMCO HONEYCOMB (JMS 0402-127-1)
PANEL E: CIBA GEIGY HONEYCOMB (KLM 261161)

FILLER X: BONDO AUTOMOTIVE FILLER
FILLER Y: HSH AEROSPACE
FILLER Z: MARTIN SENYOUR AUTOMOTIVE FILLER

FIGURE 7. EARLY SUBSTRATE/SPATULA FILLER TESTS IN OSU CHAMBER

NBS TESTS USING "BONDO" AUTOMOTIVE BODY FILLER

Panel/Filler/Test	Panel Weight (g)	Filler Weight (g)	Panel + Filler Weight (g)	D_S 2 min	D_S 4 min
A/X1	5.9	4.6	10.5	24.84	51.03
A/X2	5.9	5.8	11.7	39.77	48.89
A/X3	5.7	4.3	10.0	20.74	77.89
A/X4	5.8	4.4	10.2	X	X
		AVERAGE OF FILLED PANELS		28.45	59.27
		BASELINE PANEL A		0.0	0.0
B/X1	5.7	6.3	12.0	37.46	49.75
B/X2	5.7	9.6	15.3	211.6	202.3
B/X3	5.7	5.9	11.6	43.57	74.33
B/X4	5.6	7.9	13.5	X	X
		AVERAGE OF FILLED PANELS		97.54	108.8
		BASELINE PANEL B		0.0	0.0
C/X1	6.7	8.9	15.6	36.61	65.13
C/X2	6.8	9.4	16.2	49.86	80.25
C/X3	6.7	8.5	15.2	32.54	64.95
C/X4	6.8	10.0	16.8	X	X
		AVERAGE OF FILLED PANELS		39.67	70.11
		BASELINE PANEL C		0.71	3.79
D/X1	12.2	8.9	21.3	65.63	101.3
D/X2	12.1	10.2	22.3	64.44	88.59
D/X3	12.3	11.4	23.7	67.22	92.89
D/X4	12.0	9.7	21.7	X	X
		AVERAGE OF FILLED PANELS		65.76	94.26
		BASELINE PANEL D		22.91	34.88
E/X1	13.8	9.30	23.1	51.09	96.72
E/X2	13.3	9.20	22.5	73.48	96.24
E/X3	13.8	9.10	22.9	107.4	135.1
E/X4	13.6	10.8	24.4	X	X
		AVERAGE OF FILLED PANELS		77.32	109.4
		BASELINE PANEL E		19.28	26.03

X not tested

PANEL A: SCHNELLER CRUSH CORE
PANEL B: SCHNELLER CRUSH CORE (one-week cure time of filler)
PANEL C: JAMCO HONEYCOMB (JMS 0408-30-89)
PANEL D: JAMCO HONEYCOMB (JMS 0402-127-1)
PANEL E: CIBA GEIGY HONEYCOMB (KLM 261161)

FILLER X: BONDO AUTOMOTIVE FILLER
FILLER Y: HSH AEROSPACE FINISH
FILLER Z: MARTIN SENYOUR AUTOMOTIVE FILLER

FIGURE 8. EARLY SUBSTRATE/SPATULA FILLER TESTS IN NBS CHAMBER

NBS TESTS USING HSH AEROSPACE FILLER

Panel/Filler/Test	Panel Weight (g)	Filler Weight	Panel + Filler Weight (g)	Ds 2 min	Ds 4 min
A/Y1	5.8	6.10	11.9	129.1	192.7
A/Y2	5.8	6.70	12.5	139.7	197.7
A/Y3	5.8	6.40	12.2	127.3	178.4
A/Y4	5.8	6.40	12.2	X	X
		AVERAGE OF FILLED PANELS		132.0	189.6
			BASELINE PANEL A	0.0	0.0
B/Y1	6.0	7.10	13.1	112.0	162.0
B/Y2	6.2	6.90	13.1	125.5	182.4
B/Y3	5.7	7.50	13.2	132.8	197.9
B/Y4	5.8	6.90	12.7	X	X
		AVERAGE OF FILLED PANELS		123.4	180.8
			BASELINE PANEL B	0.0	0.0
C/Y1	6.7	12.0	18.7	137.4	181.8
C/Y2	7.9	11.2	19.1	121.6	161.6
C/Y3	6.7	12.2	18.9	140.8	187.1
C/Y4	6.7	11.9	18.6	X	X
		AVERAGE OF FILLED PANELS		133.3	176.8
			BASELINE PANEL C	0.71	3.79
D/Y1	11.9	12.2	24.1	128.1	177.3
D/Y2	12.1	12.6	24.7	141.9	200.7
D/Y3	12.4	12.5	24.9	137.1	193.4
D/Y4	11.9	12.9	24.8	X	X
		AVERAGE OF FILLED PANELS		135.7	190.5
			BASELINE PANEL D	22.91	34.88
E/Y1	13.7	12.1	25.8	137.4	236.8
E/Y2	13.0	11.8	24.8	131.1	204.9
E/Y3	12.9	11.5	24.4	146.5	233.4
E/Y4	13.7	11.7	25.4	X	X
		AVERAGE OF FILLED PANELS		138.3	225.0
			BASELINE PANEL E	19.28	26.03

X not tested

PANEL A: SCHNELLER CRUSH CORE
PANEL B: SCHNELLER CRUSH CORE (one-week cure time of filler)
PANEL C: JAMCO HONEYCOMB (JMS 0408-30-89)
PANEL D: JAMCO HONEYCOMB (JMS 0402-127-1)
PANEL E: CIBA GEIGY HONEYCOMB (KLM 261161)

FILLER X: BONDO AUTOMOTIVE FILLER
FILLER Y: HSH AEROSPACE FINISHES
FILLER Z: MARTIN SENYOUR AUTOMOTIVE FILLER

FIGURE 9. EARLY SUBSTRATE/SPATULA FILLER TESTS IN NBS CHAMBER

NBS TESTS USING MARTIN SENYOUR AUTOMOTIVE BODY FILLER

Panel/Filler/Test	Panel Weight (g)	Filler Weight (g)	Panel + Filler Weight (g)	Ds 2 min	Ds 4 min
A/Z1	5.8	5.2	11.0	25.35	67.88
A/Z2	5.9	4.7	10.6	31.69	96.72
A/Z3	5.8	5.5	11.3	34.58	84.39
A/Z4	5.8	4.6	10.4	X	X
		AVERAGE OF FILLED PANELS		30.54	82.99
			BASELINE PANEL A	0.0	0.0
B/Z1	5.9	6.2	12.1	42.55	61.79
B/Z2	5.8	7.3	13.1	59.72	117.0
B/Z3	5.8	6.9	12.7	40.04	57.66
B/Z4	5.8	5.9	11.7	X	X
		AVERAGE OF FILLED PANELS		47.44	78.82
			BASELINE PANEL B	0.0	0.0
C/Z1	6.7	9.40	16.1	46.40	88.69
C/Z2	6.7	8.70	15.4	30.23	54.71
C/Z3	6.7	11.0	17.7	41.59	86.09
C/Z4	6.8	8.80	15.6	X	X
		AVERAGE OF FILLED PANELS		39.41	76.50
			BASELINE PANEL C	0.71	3.79
D/Z1	12.2	11.0	23.2	70.30	106.3
D/Z2	12.2	10.4	22.7	48.98	108.1
D/Z3	12.6	12.3	24.9	96.44	139.4
D/Z4	11.8	16.5	28.3	X	X
		AVERAGE OF FILLED PANELS		71.91	117.9
			BASELINE PANEL D	22.91	34.88
E/Z1	13.6	12.6	26.2	100.4	127.1
E/Z2	13.9	9.30	23.2	120.4	143.3
E/Z3	13.6	10.5	24.1	60.55	76.66
E/Z4	13.1	9.50	22.6	X	X
		AVERAGE OF FILLED PANELS		93.78	115.7
			BASELINE PANEL B	19.28	26.03

X not tested

PANEL A: SCHNELLER CRUSH CORE
PANEL B: SCHNELLER CRUSH CORE (one-week cure time of filler)
PANEL C: JAMCO HONEYCOMB (JMS 0408-30-89)
PANEL D: JAMCO HONEYCOMB (JMS 0402-127-1)
PANEL E: CIBA GEIGY HONEYCOMB (KLM 261161)

FILLER X: BONDO AUTOMOTIVE FILLER
FILLER Y: HSH AEROSPACE FINISHES
FILLER Z: MARTIN SENYOUR AUTOMOTIVE FILLER

FIGURE 10. EARLY SUBSTRATE/SPATULA FILLER TESTS IN NBS CHAMBER

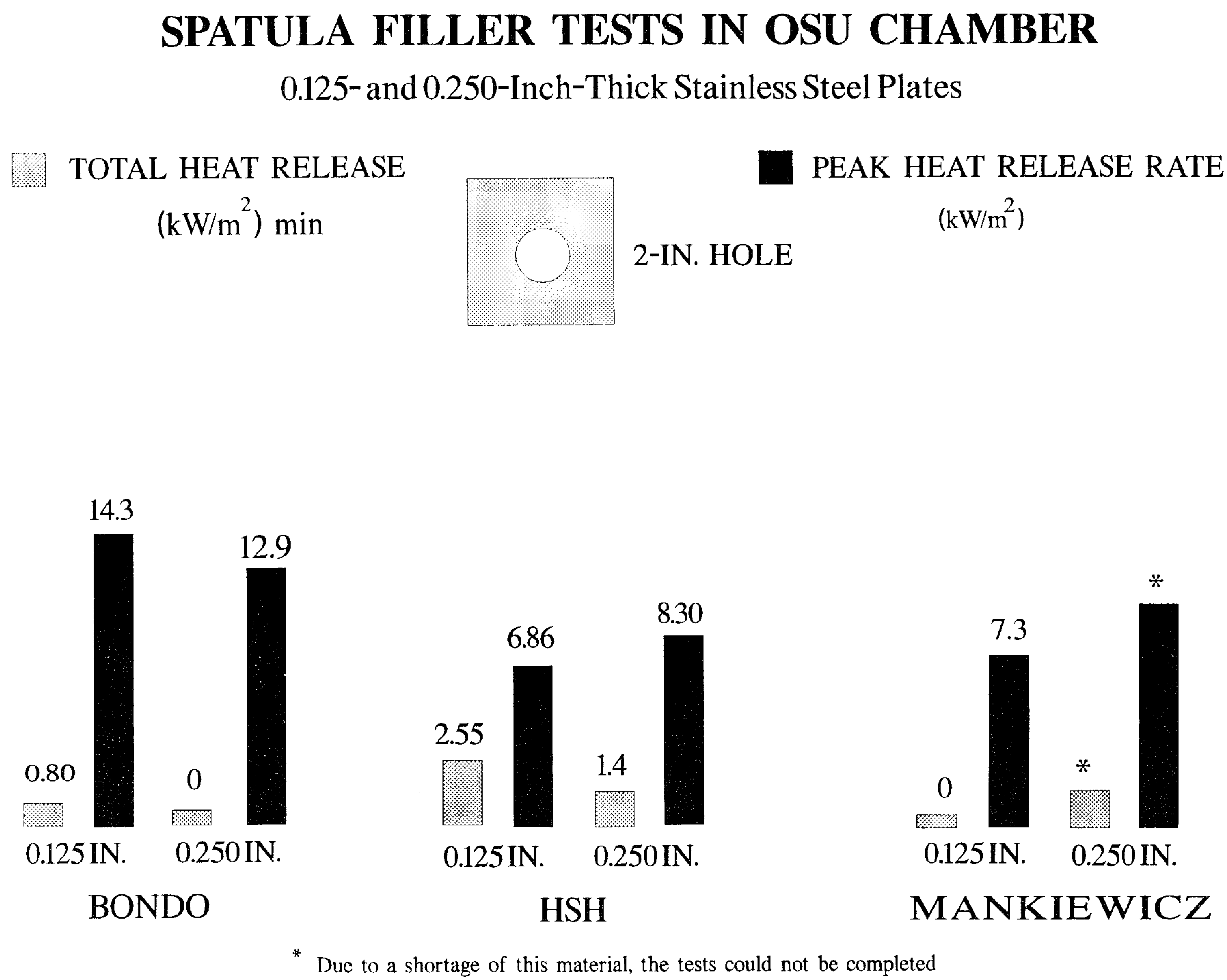


FIGURE 11. SPATULA FILLER TESTS USING STAINLESS STEEL PLATES WITH 2-INCH DIAMETER HOLES

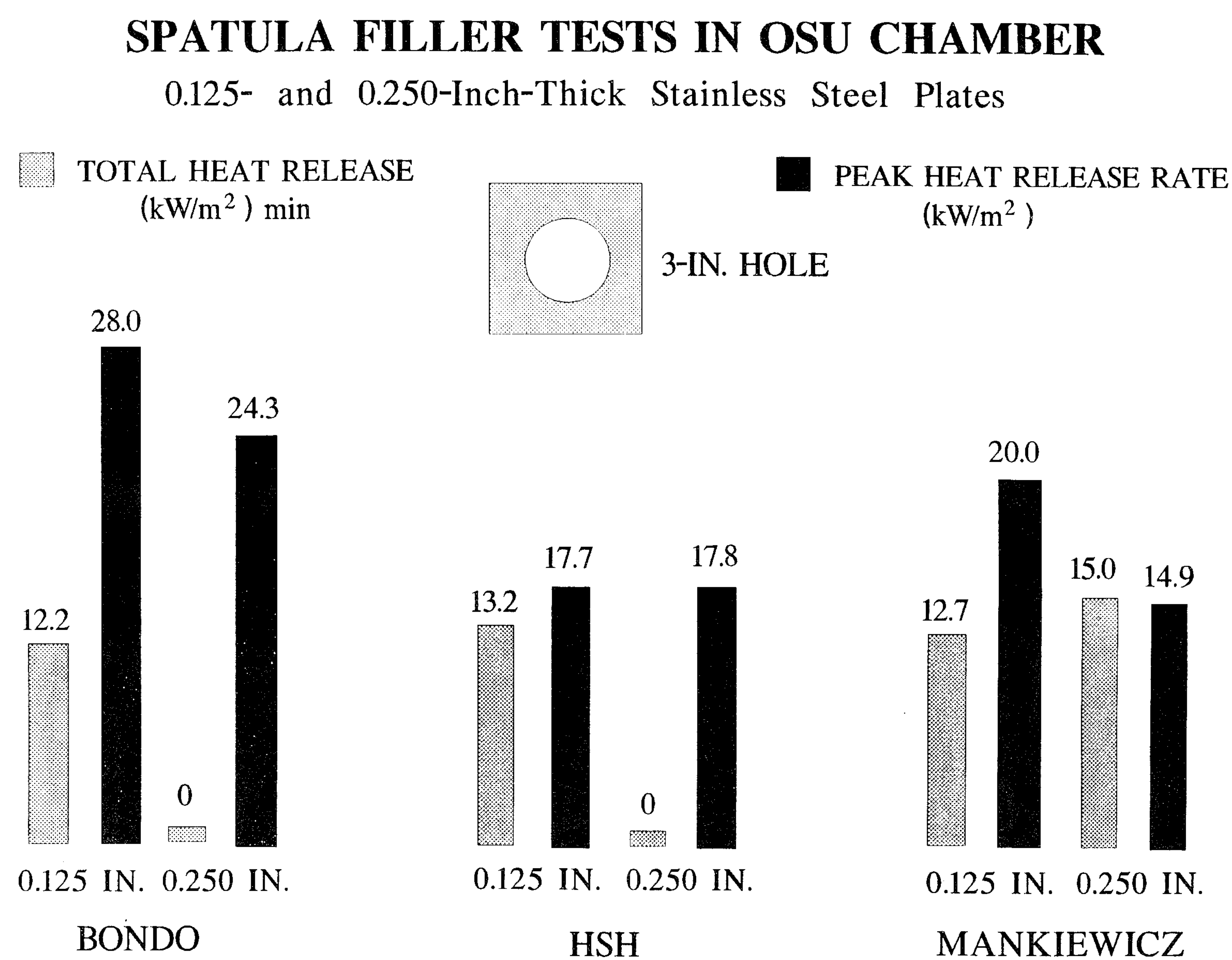


FIGURE 12. SPATULA FILLER TESTS USING STAINLESS STEEL PLATES WITH 3-INCH-DIAMETER HOLES

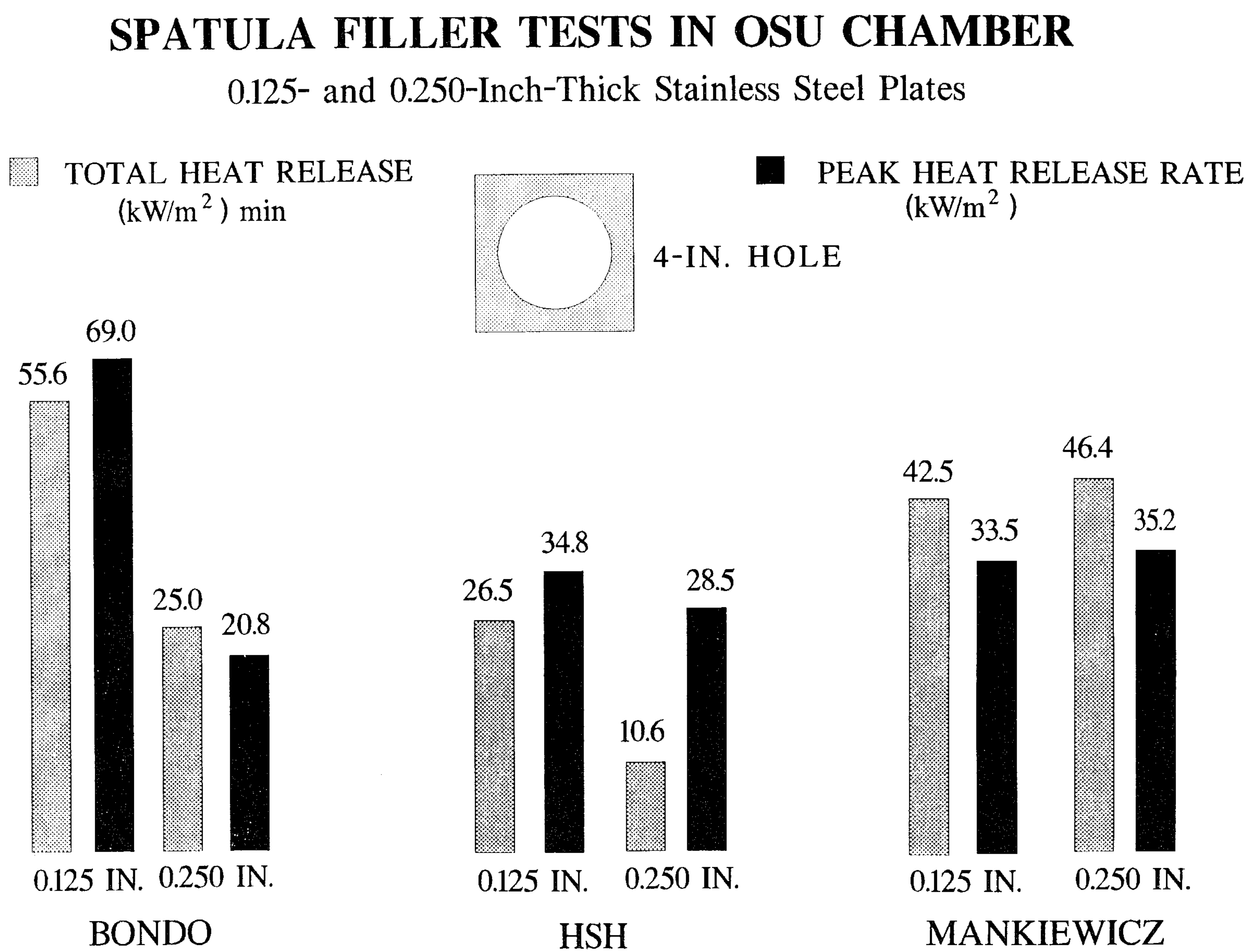
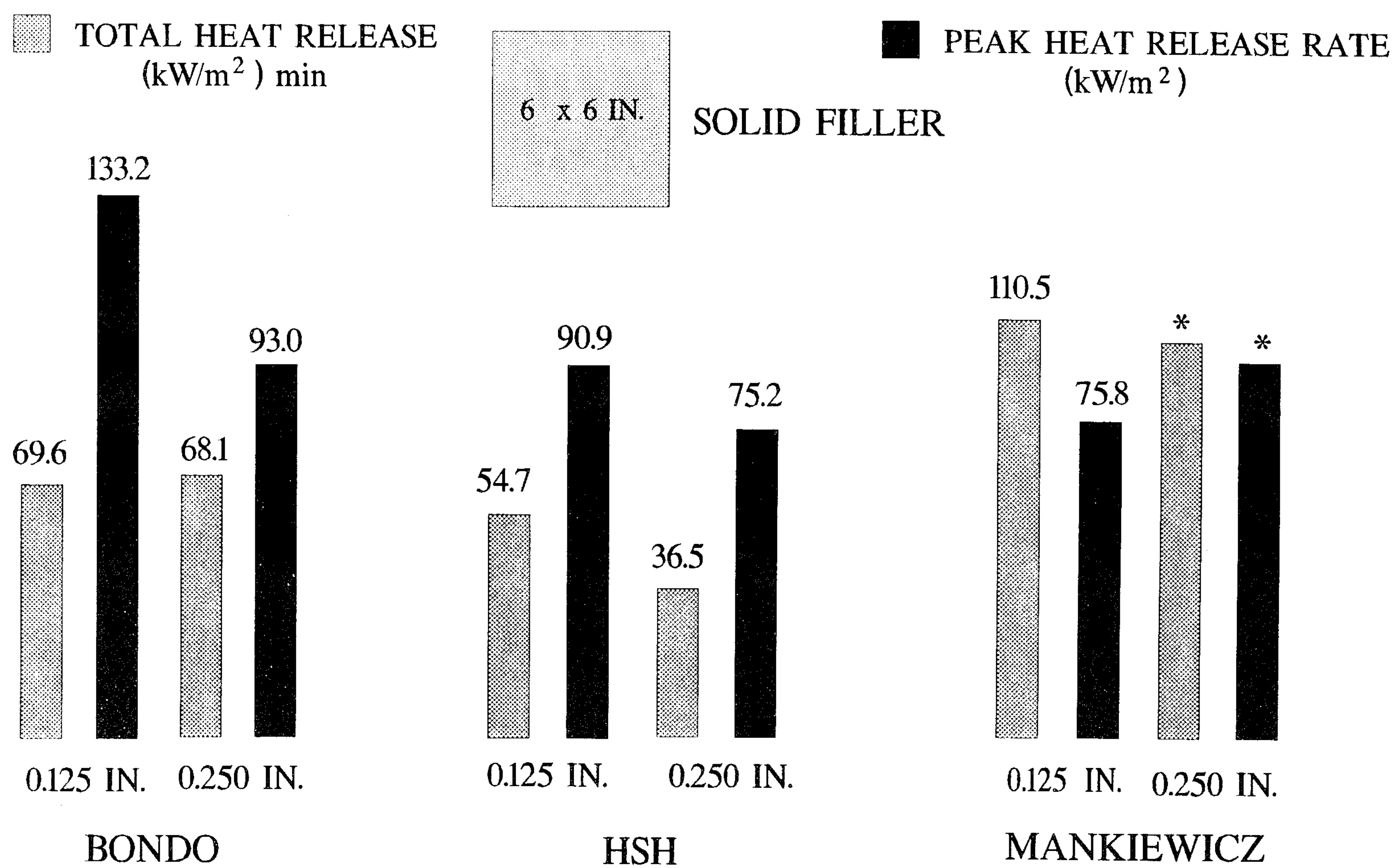


FIGURE 13. SPATULA FILLER TESTS USING STAINLESS STEEL PLATES WITH 4-INCH DIAMETER HOLES

SPATULA FILLER TESTS IN OSU CHAMBER



* Due to a shortage of this material, the tests could not be completed

FIGURE 14. SPATULA FILLER TESTS CONSISTING OF SOLID FILLER MATERIAL

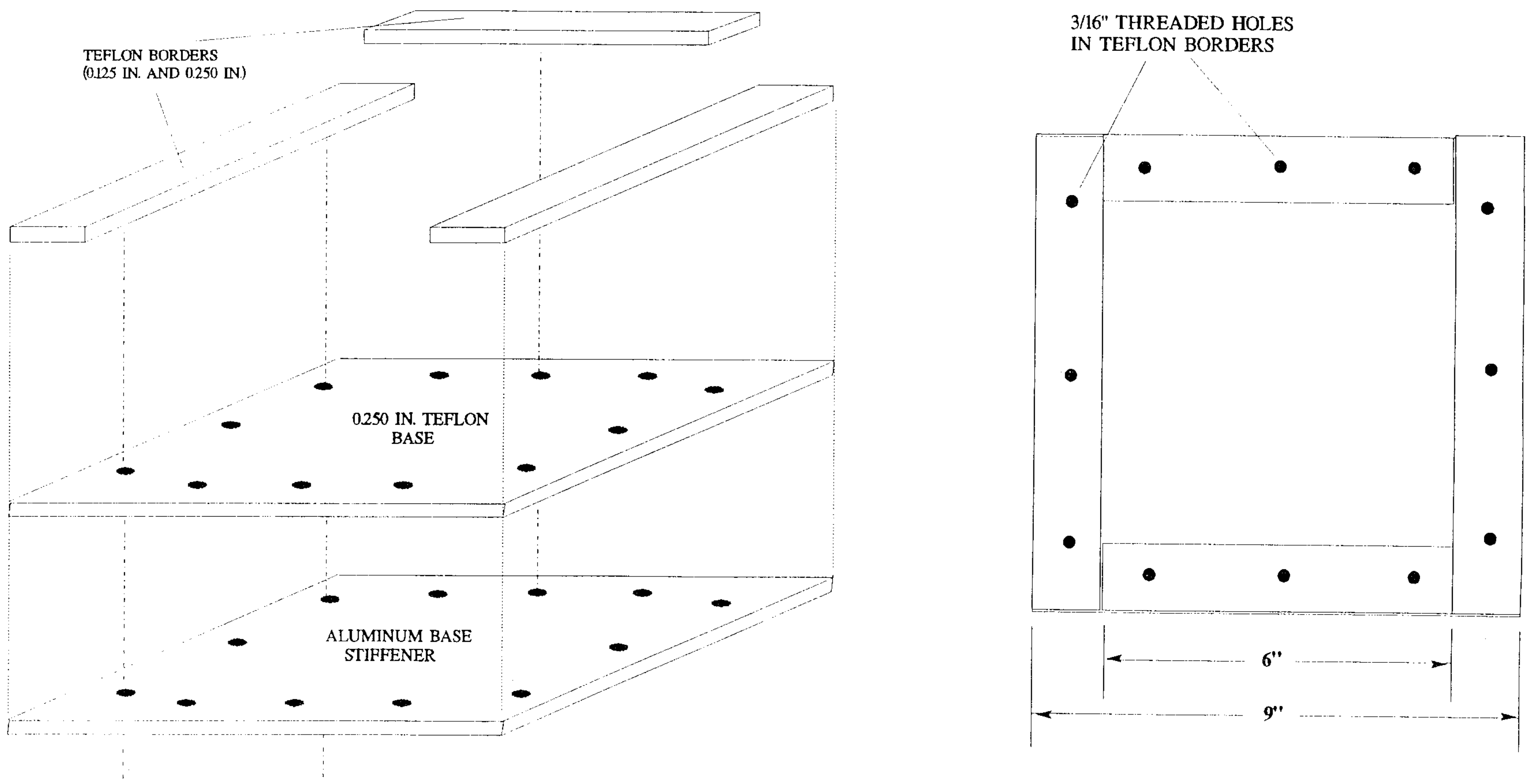


FIGURE 15. SPATULA FILLER SAMPLE MOLD

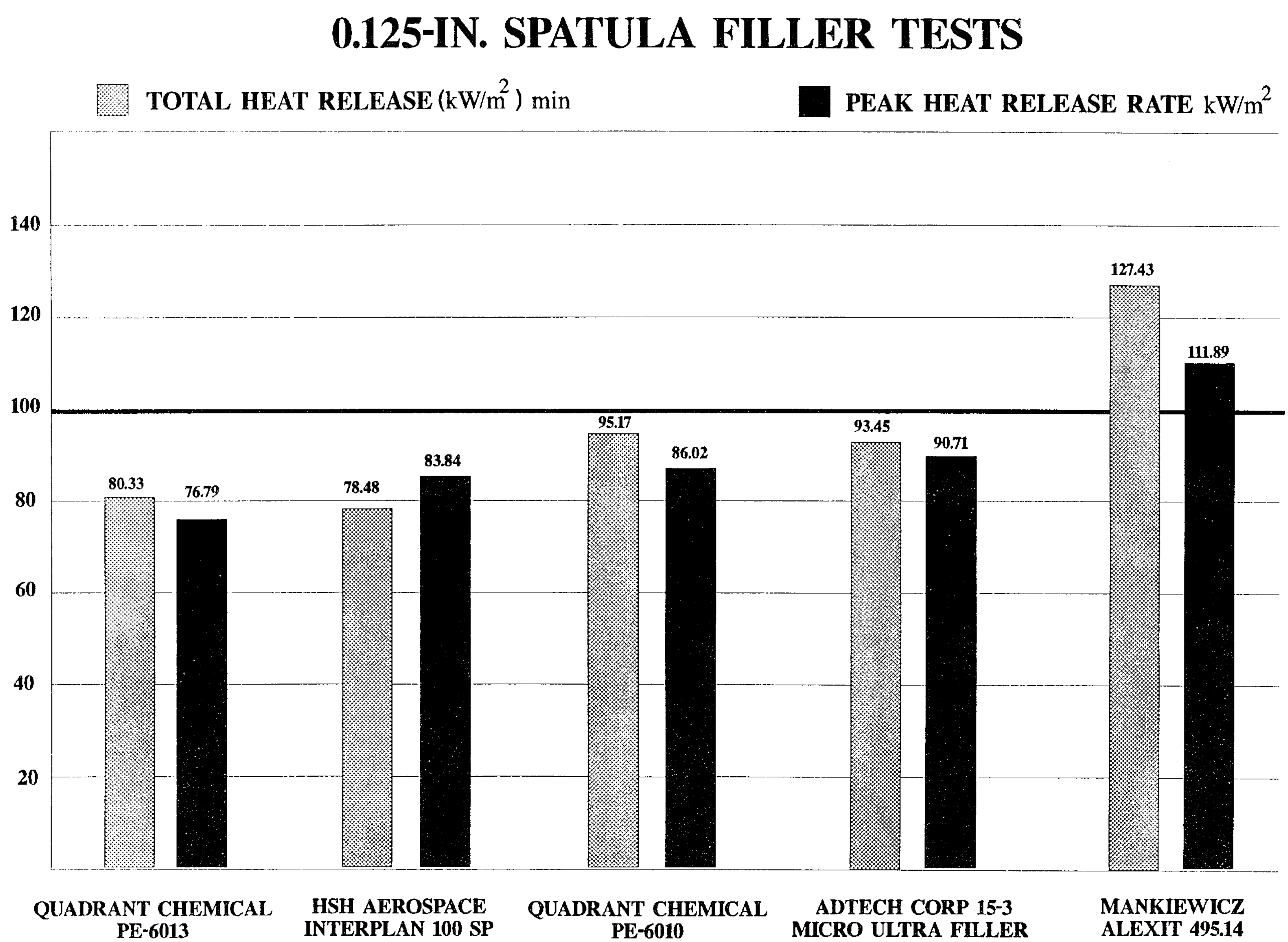


FIGURE 16. SPATULA FILLER TEST RESULTS (0.125 IN.)

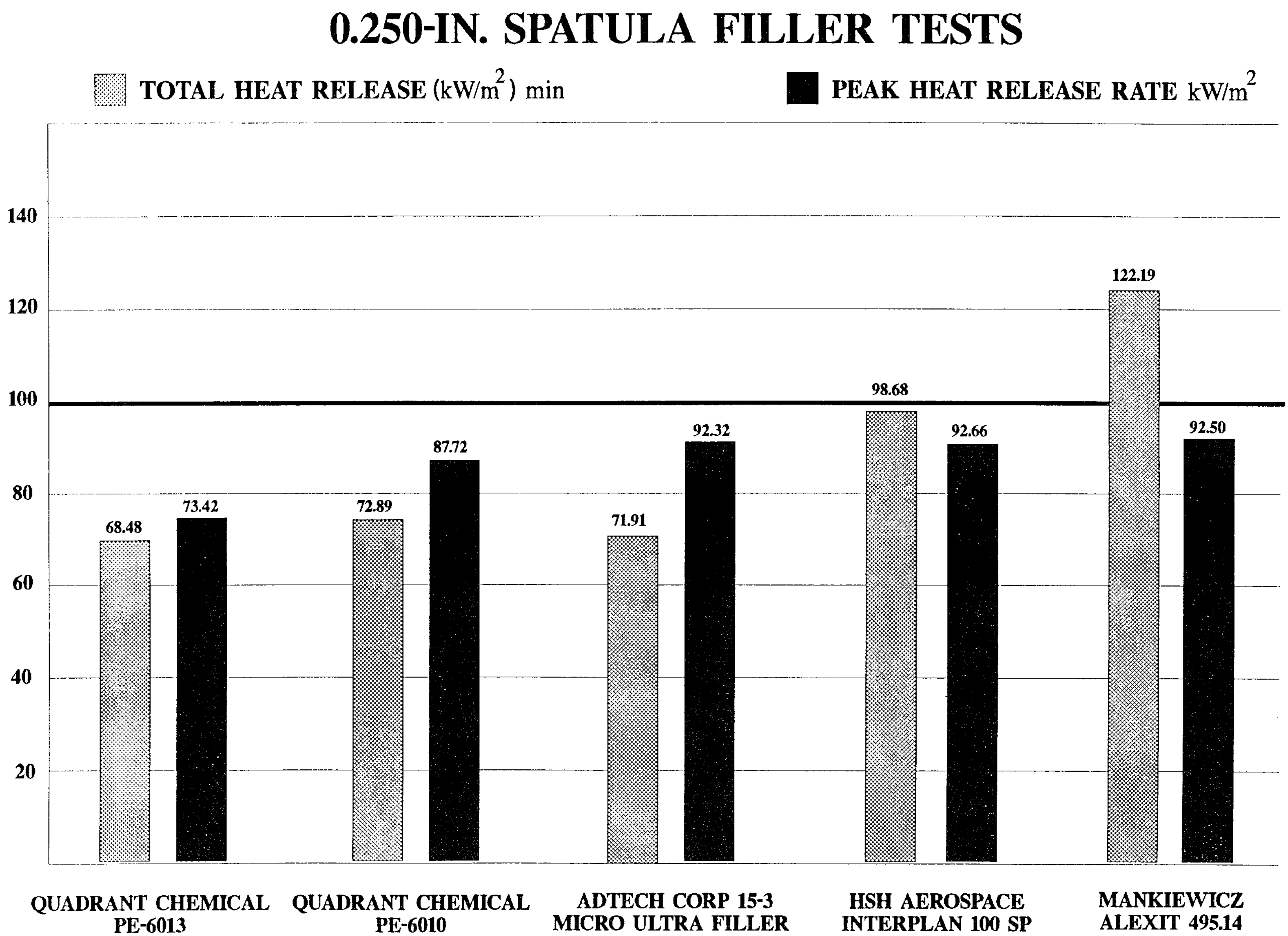


FIGURE 17. SPATULA FILLER TEST RESULTS (0.250 IN.)